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SOME EFFECTS OF SULFUR FERTILIZATION ON NODULATION AND GROWTH OF ANNUAL RANGE LEGUMES

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Growth of native annual legumes on rangeland increased greatly following applications of sulfur at the San Joaquin Experimental Range, Madera County, California (Bentley, 1946; Bentley and Green 1954; Bentley, Green and Wagnon 1959). Greater grass production during succeeding years indicated the fixation of considerable nitrogen. Not mentioned in previous reports is the observation that nodulation on roots of sulfur-fertilized legumes was stimuated by the sulfur. Root nodules of recently fertilized legumes greatly exceeded in number and size those not fertilized. In succeeding years nodule size and numbers gradually decreased until, after 4 years, they were very little larger or more numerous than where no sulfur had been applied.

This paper reports results of a study made to supplement the observation concerning effects of sulfur on nodulation.

The nodules found on legume roots are formed by the invasion of bacteria of the genus Rhizobium through the root hair. This infection injures the plant and results in the formation of a lump, or nodule, on the root. Bacteria, living in these nodules, have the ability to fix gaseous nitrogen from the atmosphere in simple and complex organic and inorganic compounds. The nitrogen compounds may be absorbed by the plant, or they become available on decomposition of the nodule. The plant, in turn, supplies the carbohydrate needs of the bacteria (Millar, Turk, and Foth, 1958; Waksman, 1952).

In a greenhouse experiment, Invanoff (1948), using sulfur to correct lime-induced chlorosis in cowpeas on calcareous soil, found that nodulation was increased. Greatest average nodule weight per plant occurred where sulfur application had been heaviest. Nodulation was also correlated with intensity of green color in the leaf,

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the greenest plants showing more and larger nodules. Anderson and Spencer (1949) reported that sulfur deficiency decreased number and size of nodules on subterranean clover plants in New South Wales. Their evidence showed that sulfur deficiency will reduce symbiotic nitrogen fixation and yield and nitrogen content of legumes.

The Study Area

The San Joaquin Experimental Range is located in the Sierra Nevada foothills in Madera County, California. Its topography is rolling, the elevation 700 to 1,700 feet. The granitic sandy loam soil is of the Vista series. Soil reaction is about pH 6.8. Winters are generally mild and rainy, summers hot and dry (Talbot, Nelson, and Storie, 1942).

Plant growth is limited by lack of rainfall, low temperatures, or both during the fall and winter months. Rapid plant growth does not occur until mid-February or later (Bentley and Talbot, 1951).

Herbaceous vegetation consists of a wide variety of annual grasses and forbs, and a few perennials. Legumes occur naturally, and include several species of clover (Trifolium), wild trefoil (Lotus), and lupines (Lupinus). Bur clover (Medicago hispida) grows sparingly on the Experimental Range, and was not encountered in this study.

Procedure

Gypsum, containing sulfur at about 65 pounds per acre, was broadcast on a previously unfertilized range area in October 1951. A similar adjoining range was not fertilized.

Precipitation during the following months was above average, and totaled 24.7 inches during the 1951-52 year. Herbaceous plants grew slowly during the winter because of low temperatures, but rapidly starting about March 1, 1952. Plants were collected for nodule study during the early part of this period of rapid spring growth.

Similar west, north, and east slopes of up to 15 percent gradient were selected in both areas. A square-foot frame was dropped at intervals along a compass line down each slope so that each exposure was sampled with 10 quadrats. Sod within each frame was carefully removed, and the legumes separated from the soil and other vegetation. Legume plants, segregated by species, were placed in paper envelopes and allowed to dry. Roots were later removed and soaked in water for 24 hours. Nodules, swollen to about former normal size, were picked off the roots and counted. They were next placed in a laboratory desiccator for 5 days, and weighed.

Results

Sulfur fertilization increased the number and weight of nodules as well as the size and number of legume plants. Nodule numbers were nearly doubled, on the average, where sulfur had been recently applied (table 1). White tip clover (Trifolium variegatum), which grows on moist lower slopes and swales, had the greatest number of nodules per plant, but they were small. Fineleaf lotus (Lotus strigosus), a plant which grows on shallow, dry slope soil, had the fewest nodules.

Nodule numbers on Spanish clover (Lotus americanus), fineleaf lotus, tree clover (Trifolium ciliolatum), littlehead clover (T. microcephalum), and whitetip clover were approximately doubled on fertilized range. On silverleaf lotus (Lotus subpinnatus), nodule numbers increased more than 5 times. On ground lupine(Lupinus bicolor) nodule growth was continuous or sometimes intermittent, up to the root, and could not be counted as individual nodules.

Nodule weight averaged more than 700 percent greater (table 1). Percentagewise, the greatest and the least increases following fertilization were on silverleaf lotus and fineleaf lotus, respectively. The greatest actual weight change, by far, was on ground lupine, which had an increase in nodule weight per plant of 39 milligrams compared to an average of 8.5 milligrams. Weight of nodules on the three clover species increased between three and four times.

Sulfur fertilization increased herbage production in all seven legume species collected (table 2). There were two reasons: greater average size of plant and greater survival of legume plants on the fertilized range.

The species were not equally affected. Spanish clover, fineleaf lotus, and whitetip clover numbers appeared unchanged. Littlehead clover plants doubled in number from 14 to 28 per square foot, and silverleaf lotus numbers increased tenfold. Tree clover and ground lupine were between these extremes. For all species average plants per square foot doubled from 3.5 to 7.7.

Average plant size was increased 4.6 times. One clover failed to double in size following sulfur fertilization, and two species of Lotus just doubled. Size of the other species increased from 4 to 8 times on fertilized range.

Herbage production increased from 100 pounds per acre on unfertilized range to 1,186 pounds. Thus production of legume herbage was 1,086 pounds greater following fertilization. This difference would have been considerably greater had the sampling been done at plant maturity rather than early in the spring growing period.

Table 1.--Number and dry weight of nodules on rangeland legume plants following sulfur fertilization[1/]

Plant species	Fertilized range			Unfertilized range			Difference		
	No. per plant	Wt. per plant	Wt. per acre	No. per plant	Wt. per plant	Wt. per acre	No. per plant	Wt. per plant	Wt. per acre
		mg.	lbs.		mg.	lbs.		mg.	lbs.
Spanish clover	11.14	3.2	.52	6.55	1.5	.33	4.59	1.7	.19
Fineleaf lotus	4.00	0.6	.004	2.00	0.4	.001	2.00	.2	.003
Silverleaf lotus	12.17	11.4	2.19	2.13	0.3	.006	10.04	11.1	2.18
Ground lupine	2/6.90	42.6	25.36	6.65	3.6	.55	.25	39.0	24.81
Tree clover	15.71	2.6	3.11	8.69	0.7	.11	7.02	1.9	3.00
Littlehead clover	12.67	1.6	4.35	7.51	0.4	.56	5.16	1.2	3.79
Whitetip clover	34.00	6.1	1.93	16.50	1.9	.71	17.50	4.2	1.22
Average or Total	13.80	9.7	37.46	7.15	1.2	2.27	6.65	8.5	35.19

1/ Nodule counts were made by Robert D. Smith while a student at California State Polytechnic College, San Luis Obispo, California.

2/ Nodules on roots of ground lupine were enlarged and clustered in clumps, therefore, individuals were difficult to distinguish.

Table 2.-- Number and air dry weight of rangeland legume plants at the end of the winter growth period following sulfur fertilization

Plant species	Fertilized range			Unfertilized range			Difference		
	Plants		Wt. per acre	Plants		Wt. per acre	Plants		Wt. per acre
	Av. no. per sq. ft.	Avg. wt.		Av. no. per sq. ft.	Avg. wt.		Av. no. per sq. ft.	Avg. wt.	
		gms.	lbs.		gms.	lbs.		gms.	lbs.
Spanish clover	1.7	.121	19.7	2.3	.061	13.4	-0.6	.060	6.3
Fineleaf lotus	0.07	.070	0.5	0.03	.040	0.1	.04	.030	0.4
Silvertip lotus	2.0	.242	46.4	0.2	.039	0.7	1.8	.203	45.7
Ground lupine	6.2	.804	477.8	1.6	.095	14.6	4.6	.709	463.2
Tree clover	12.4	.113	134.3	1.7	.071	11.6	10.7	.042	122.7
Littlehead clover	28.3	.170	459.3	14.6	.036	50.5	13.7	.134	408.8
Whitetip clover	3.3	.152	48.2	3.9	.025	9.4	-.6	.127	38.8
Average or Total	7.7	.239	1186.2	3.5	.052	100.3	4.2	.187	1085.9

Discussion

The herbage production shown in table 2 is probably somewhat greater than should be expected throughout a pasture and in an average year. Precipitation was favorable for growth of annual vegetation, and for the year, above average. Annual legumes are responsive to a high rainfall year, and growth was greater than during drier seasons. Also, there was no suitable south slope available for sampling although some of the east and west exposures were southeast or southwest. South exposure is usually drier than the others, and range pastures facing the sun usually produce fewer legumes.

As forage plants, the clovers included in the sampling are highly palatable and preferred by livestock. The wild trefoils and lupines are mostly unpalatable, and except for Spanish clover, contribute little or nothing to the livestock diet (Green, Wagnon, and Bentley, 1958). In range condition classification, they are rated as not very desirable plants. But their nodule production, averaging more than 4 times as great per plant as on the clovers, suggests that for nitrogen fixation they may be highly important. Ground lupine is especially noteworthy.

Summary

Nodules on annual range legumes were observed to be much larger and more numerous following sulfur fertilization. To get additional information, fertilized and unfertilized range legumes were sampled in March, near the start of the rapid growth period.

On sulfur-fertilized range, numbers of nodules per plant doubled, on the average, from 7.15 to 13.80 per plant. Nodule weight per plant increased about 8 times, from dry weights of 1.2 to 9.7 milligrams per plant.

There were about twice as many legume plants per acre on fertilized range. Each plant weighed almost 5 times as much as those not sulfur fertilized. Legume herbage production was a thousand pounds per acre greater on the fertilized range. Such an increase probably could not be expected on poorer soil or in years of lesser rainfall.

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